Orbit Length Stabilization Project

Paul Lebrun, with much help and guidance from
Martin Hu, Cons Gattuso, Stan Pruss……

June 22 + 7 = 29, 2005

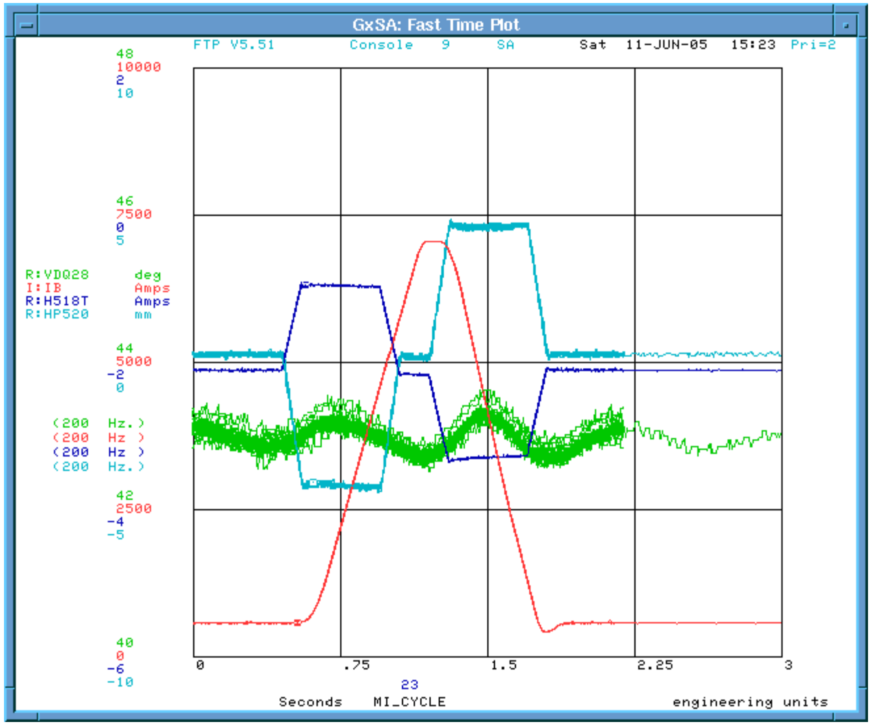
Outline

- Status of the software
- Current studies
  - Principle
  - 4-bump Optic checks
  - 4-bump correction shape and amplitude, scans.
  - 5-bump scans, local and non-local
  - Caveat: Seemingly random VDQ Phase jumps
    - Fixed, June 27 !!!
- Beam Physics Issues
  - QCL vs 4 or 5-bump correction
  - Interpretation of current results
- Plans & future studies
  - Dedicated timeline
  - Parasitic, leftover pbars (once cold)
  - Moderate stash, cooling performance.
  - Other ramps

Status of the software

- VDQ28 Fitting OAC
  - Just running fine, stable. Saving individual Snapshot, typically for every three ramps.
  - And fitting, writing to local files, reporting to ACNET
- Controlling the Ramp cards,
  - Only the F(t) table,
    - I promise, I won't change anymore the interrups or pointer tables! (there was need to..)
  - 4-bump coded up, has been easily be extended to a 5-bump, or multiple bumps, if need be.
  - Utility script to scan versus ramp parameter.
- Offline Analysis: sometimes done in Java, lately in C++/Root
  - A detail you don't need to know, unless you want to do some analysis on this data… (Help is always welcome..)
    - I try to complete the e-log with offline plots, because scans can not be interpreted without this offline analysis step.
- Left to implement, if need be:
  - Automate search for a minimum of the fitted peak to peak oscillation..
  - "Adaptive algorithm"

Principle, Online Plot.



I:IB : MI ramp current

R:H518T : 4-bump value, at 518

(R:H520, R:H522, R:H524 follow the same shape, value set to be closed orbit.)

R:HP520 : Hor. BPM at 520.

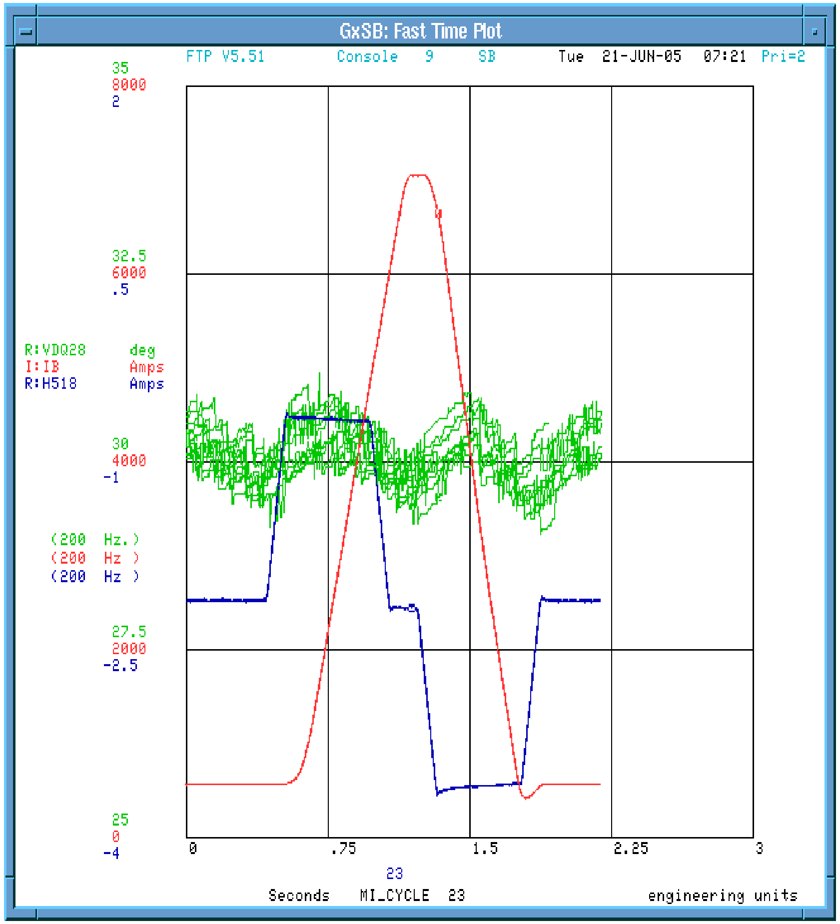
R:VDQ28 : Phase Oscillation bunch/r.f., "in degrees of 53 MHz "

- Use proton (few days ago) or leftover pbar after shots to Tev. ~ 5 to 10 e10, (pbar) or 40 e10 (proton). If pbar, long emitt ~ 10 eV.sec.
- Place the pbar or proton beam in a linear bucket, typical r.f ramp time of ~ 4.8 μsec
- With QCLP on, peak to peak oscillation of VDQ of ~ .25 to .3 degrees, on 0x23
- Turn QCLP off!, turn on the 4-bump designed by Stan and Meiquin.
- Watch these devices: MI ramp, bump setting, BPM reading at 520, record VDQ28 traces. Fit VDQ28 real time. Record all parameters of this fits in files on compute node dce08.
- Then, play with the parameter of the 4-bump during 0x23 cycles, varying both the shape and amplitude.

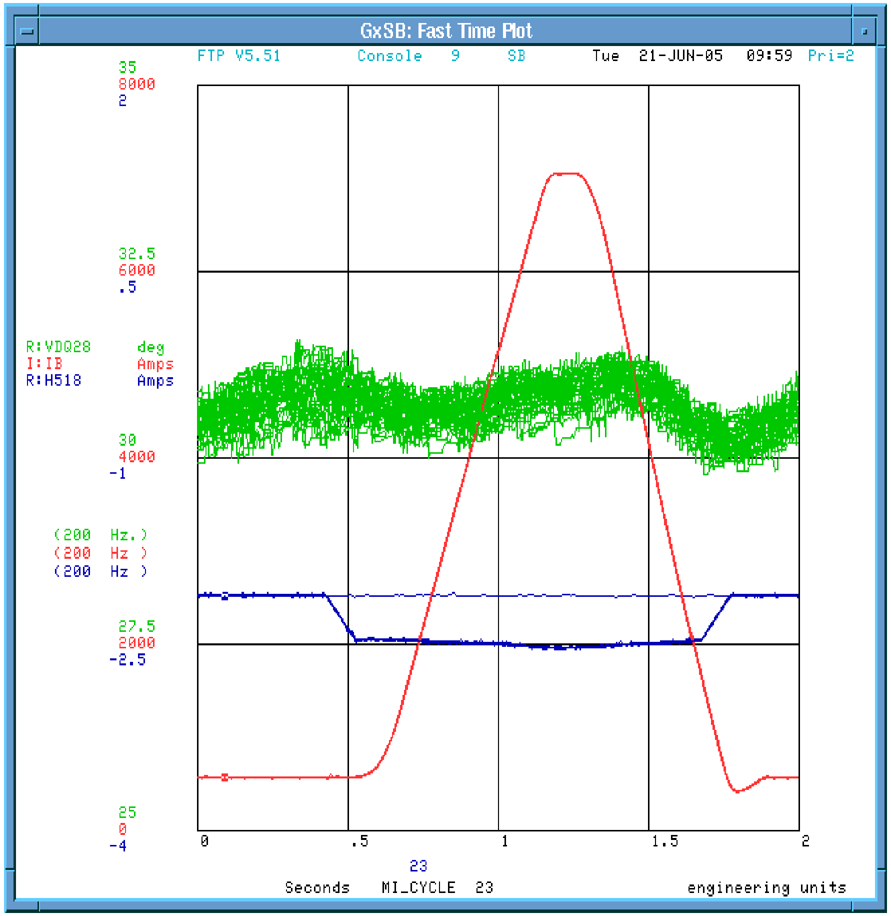
Type of scans, Cost for HEP

- On the 0x23 cycles
- 4-bump vs 5-bump
- Versus amplitude of the bump. Up to ~ 1 cm bump
- … asymmetric amplitude up/down ramp
- …. start time with respect to the MI ramp
- ….. duration of the bump
  - This is tedious (I'll show scan results in a few slides…)
- Cost to HEP (so far!) 10.8 e10 pbars (yesterday, 16:30).
  - Little or no excuse! (I had my tea and my cookies ½ hour before)
    - The beam was too cold and/or bucket width too small
    - I tried to place a bigger bump, to increase synchroton motion
    - At +2.75 Amps for H518, I was too far, stopped it, while coming back down, the C453 cards updated themselves, sequentially, such that this large bump became non-local, and I scrape it..
  - Fix is easy: not going past 1.5 Amps at H518, re-heat the beam if need be, and perhaps make the transition smoother (complicated, I don't control the timeline!)

Bump Shapes studied on Summer Solstice. (yesterday)

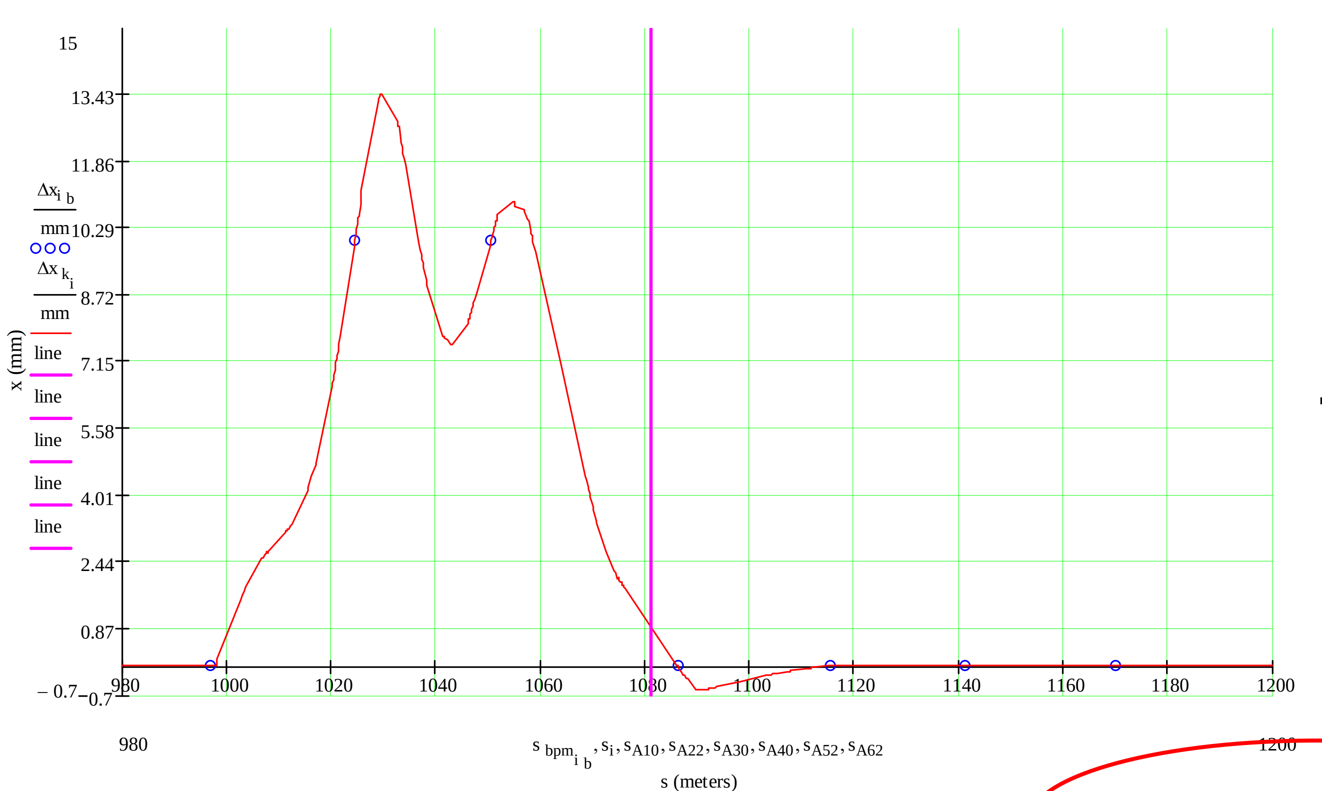


Bipolar



One bump

4-Bump, Horizontal Plane, 518-520



Orbit length difference: dll=0.~~00898~~mm

940 +- 10 µm

- Courtesy – Meiqin Xiao.. This bump is made a location where little or no change of betatron tune is expected, e.g., no sextupole feed-down. We are making progress at refining the 940 microns estimate.

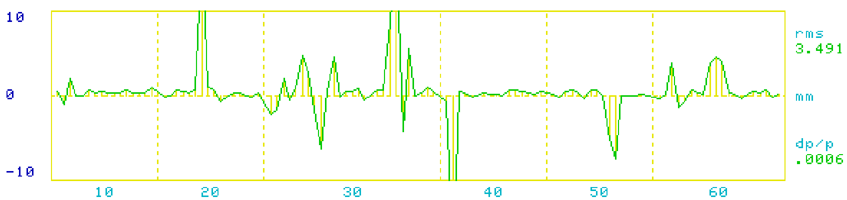
Check that this bump is closed:

GxPB 2: Recycler BPM Plot

Recycler BPM Plot

DISPLAY - Frame 0 Horizontal 17-JUN-2005 06:45:30

100	.507	232	.326	406	.3504	606	3.951		
102	-.9617	301	-2.144	408	-.1455	608	-1.451		
104	2.074	302A	-1.781	410	-.054	610	-.7119		
106	-.014	302B	1.979	412	.2928	612	.5986		
108	.0333	303	-.5873	414	.1829	614	.4076		
110	.5989	304	.9162	416	.162	616	.2117		
112	.3257	305B	4.695	418	-.0615	618	3.893		
114	.5164	305C	2.65	420	.6457	620	4.514		
116	.3334	307C	-1.739	422	.683	622	4.147		
118	.3526	307B	-6.343	424	.5268	624	.2738		
120	.3827	307A	.4687	426	.3752	626	.1092		
122	.6252	308A	4.587	428	.2002	628	-.4177		
124	.3827	310	-.2396	430	.4922	630	.1041		
126	.355	312	.4246	502	.0978	632	.4218		
128	.2927	314	.455	504	-.188	634	.3971		
130	1.005	316	.8222	506	.4929	636	.6036		
202	-.1032	318	-.4795	508	.6751	638	-.1224		
204	-.0469	320	.2023	510	.2841	640	.0879		
206	.6084	322	.7053	512	-.3088				
208	.566	324	.7118	514	.7386				
210	.3879	326	8.663	516	.6579				
212	.6135	328	19.27	518	.0536				
214	16.26	330	-4.307	520	-5.135				
216	.945	332	5.581	522	-7.521				
218	.6287	334	.038	524	-.0847				
220	-.622	336	.315	526	-.072				
222	-.2223	338	.9865	528	.0485				
224	.3581	340	.4852	530	.1455				
226	.3907	400	-.6843	532	.0118				
228	-.0249	402	-19.49	602	-.372				
230	-.1172	404	.4329	604	.2029				

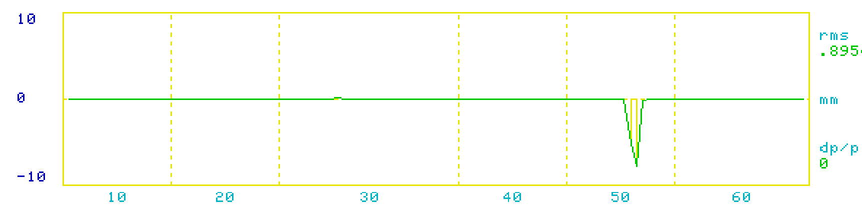


GxPB 2: BPM DIFF Plot: 491 - 490

BPM DIFF Plot: 491 - 490

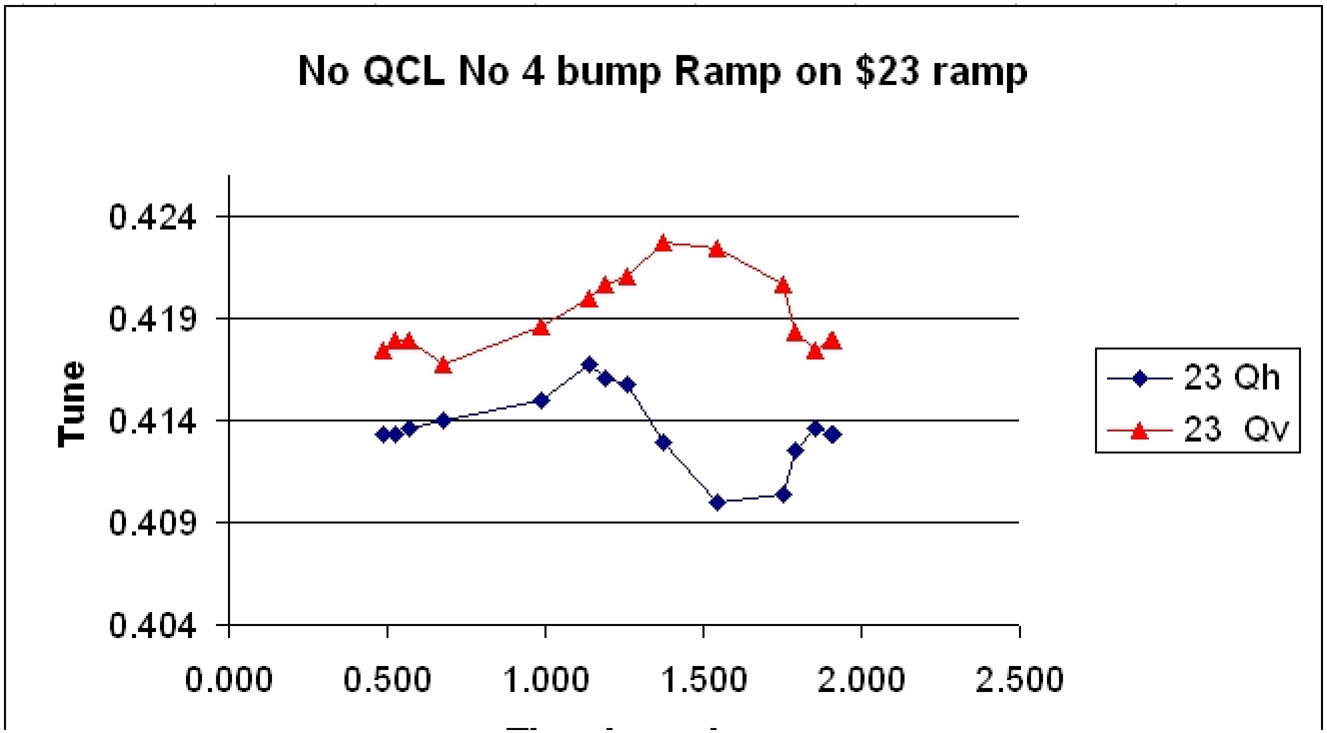
display - Frame 0 Horizontal 17-JUN-2005 06:45:30

100	.0293	232	-.0391	406	-.0313	606	-.0225
102	-.017	301	-.0216	408	-.0057	608	.0439
104	-.0373	302A	-.014	410	.0188	610	.0076
106	.0077	302B	.0648	412	-.0267	612	-.0429
108	.0282	303	.0092	414	-.063	614	-.0224
110	-.0143	304	-.0203	416	.0068	616	.0089
112	-.0373	305B	-.0265	418	.0168	618	-.0036
114	-.0166	305C	-.0472	420	-.0054	620	-.0349
116	.0189	307C	.0094	422	-.0272	622	-.0144
118	-.0041	307B	.072	424	-.0018	624	.0152
120	-.0402	307A	-.0367	426	.0087	626	.0118
122	-.0134	308A	-.0011	428	.0007	628	-.0403
124	.0087	310	.0329	430	-.0363	630	-.0186
126	.0132	312	-.0233	502	-.0351	632	.0128
128	-.0299	314	-.0341	504	.0189	634	.0124
130	-.0284	316	-.0136	506	.0263	636	-.0318
202	.0075	318	.0216	508	-.0239	638	-.024
204	.0195	320	.002	510	-.0445	640	.0095
206	-.0296	322	-.0394	512	.0046		
208	-.0209	324	-.0084	514	.0126		
210	-.013	326	.0327	516	-.0204		
212	.0227	328	-.0109	518	-.0234		
214	-.0154	330	-.0404	520	-5.27		
216	-.0443	332	-.0271	522	-7.819		
218	.0095	334	.0213	524	-.1472		
220	.0274	336	.0008	526	-.0027		
222	-.0048	338	-.0334	528	-.0464		
224	-.0252	340	-.0237	530	-.0246		
226	-.023	400	.0011	532	.0394		
228	-.0006	402	.0175	602	.0361		
230	-.0061	404	-.0104	604	-.0325		



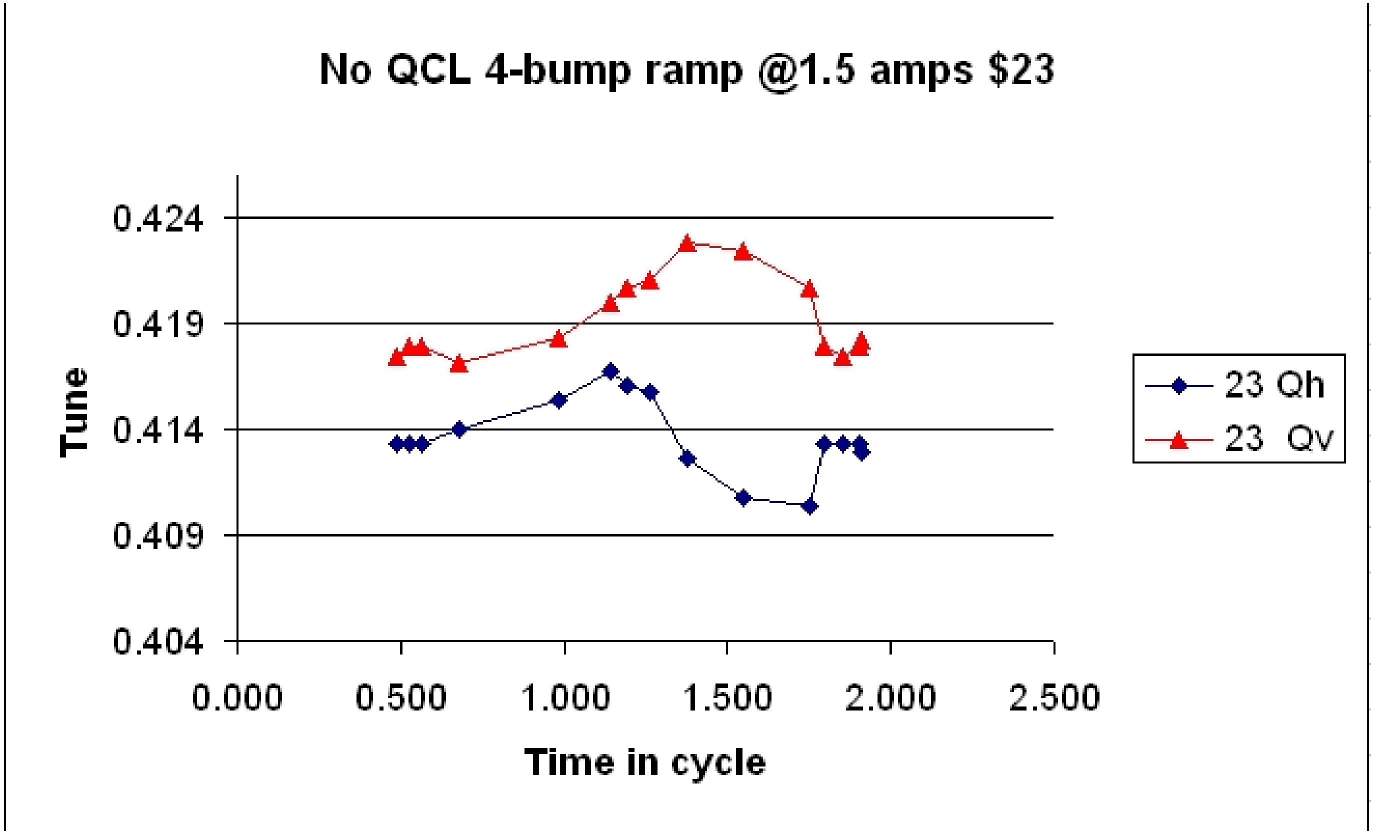
Left: Horizontal Orbit, with the ~ 6 mm 4-bump, left, difference with 4-bump On/Off. Check made on June 17, 06:45 A.M.

Check that tune across the 0x23 cycle, No QCL (1)



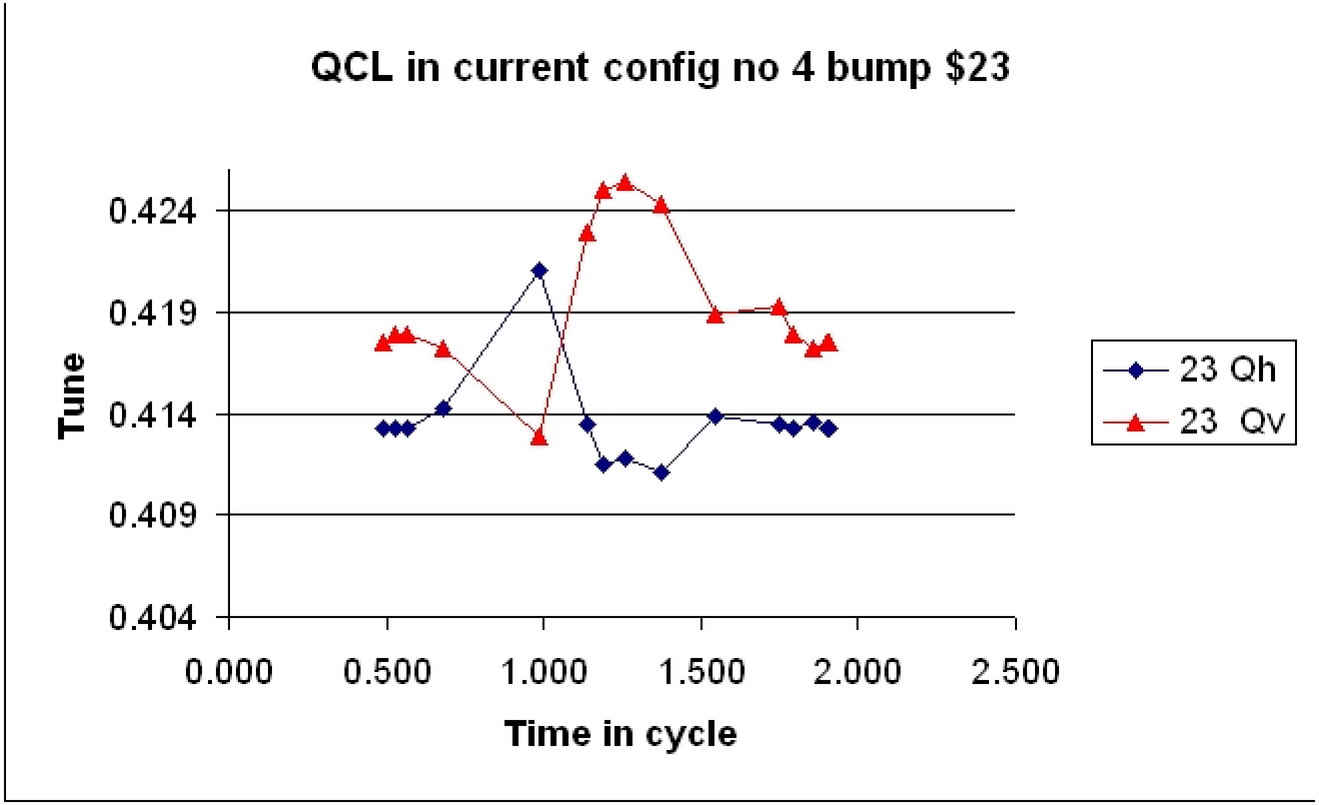
No 4 bump. Tune moves, orbit is only partially corrected for the MI ramp.

Check that tune across the 0x23 cycle, No QCL (2)



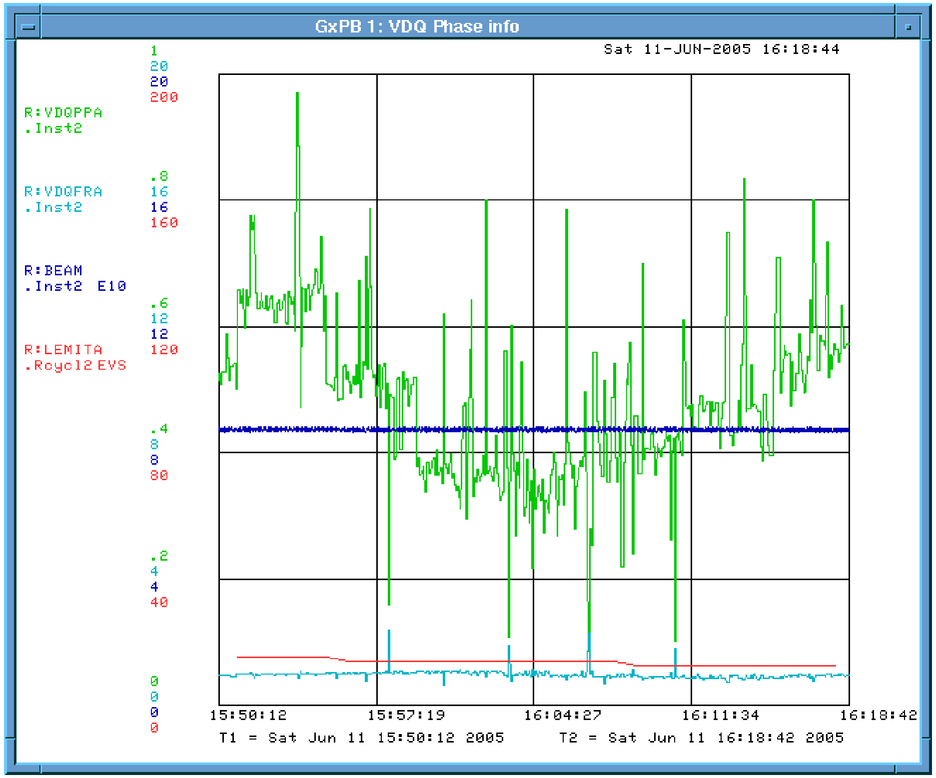
With 4 bump. Tune moves more or less in the same way (This is what we wanted!)

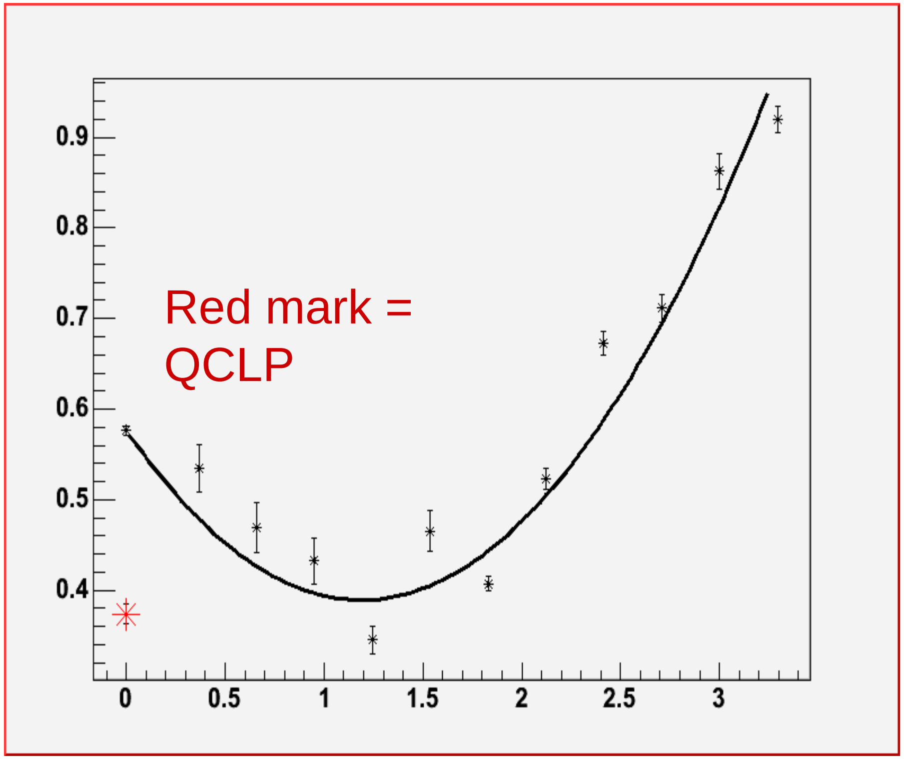
Check that tune across the 0x23 cycle, With QCL



Without 4 bump, but QCL is On Tune are moving more, and crossing. To be avoided....

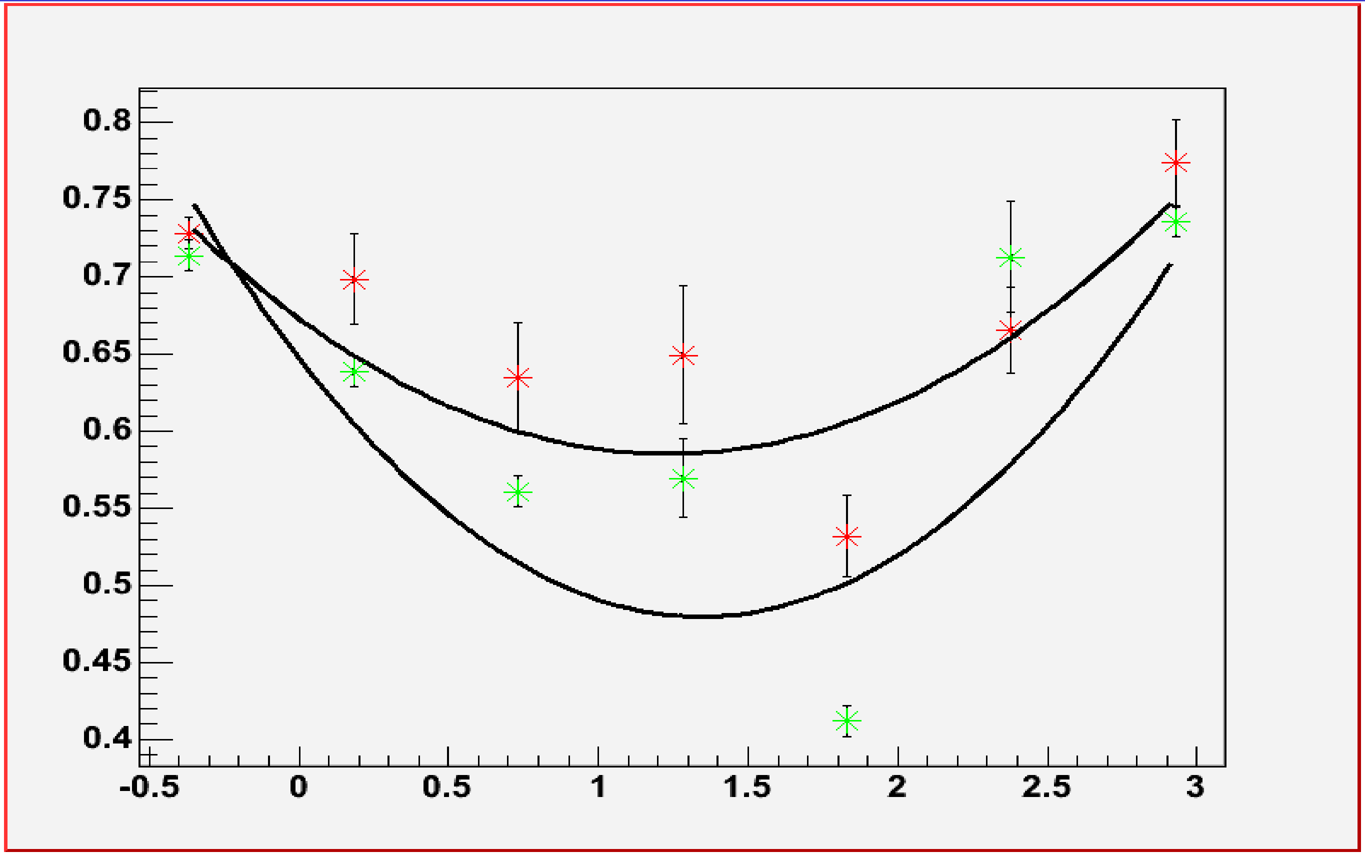
Results, Example





- Shown on the left is a real-time plot (D44) of the fitted peak to peak maximum VDQ28 (R:VDQPPA) vs time , as we change the ramp, scanning various parameters (bump height, duration, time delay… (Also shown is the fitted frequency (R:BDQFRA), R:Beam, and Long Long emit. Not shown is the set value of the scan.
- Shown on the right is the result of offline analysis, filtering off the non 0x23 events, selecting the fits with acceptable synchrotron frequency. The Peak to Peak max. amplitude, of VDQ28, fitted, is shown versus the bump current. Done with Pbar, On Saturday June 11.

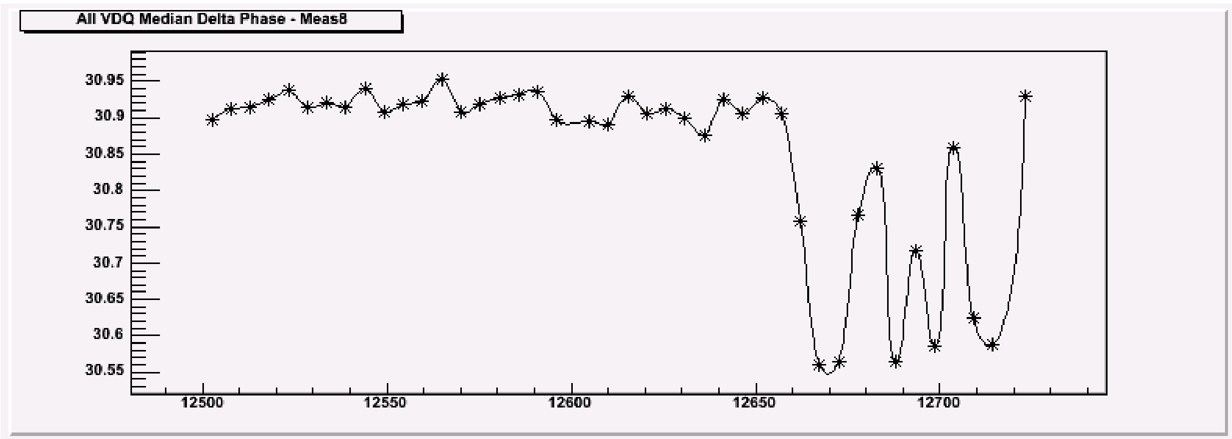
Quality of the data from such scans, Reproducibility?



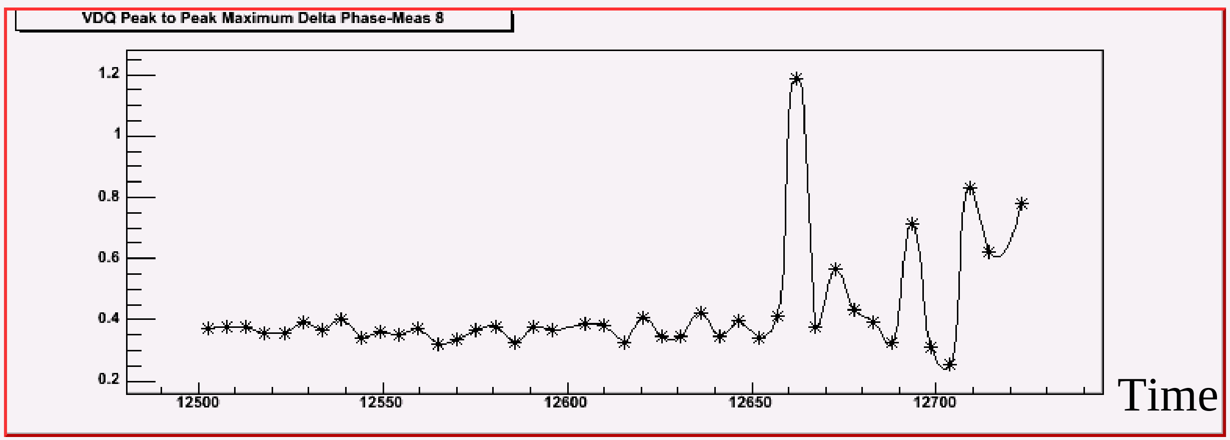
- Shown are two consecutive scans for the bipolar bump, as shown on slide 4, versus the amplitude of this bump. The error bar comes from a straight statistical analysis of the ~ 30 to 40 ramps taken at each setting. The green and red sets don't agree, setting to setting. However, in average, the optimum current seems to be consistent, around 1.5 Amps.

Unaccounted variations.

<Phase>



Peak to Peak Phase variation



Time !

- Top: the average of the maximum/minimum of VDQ28 phase during a 0x23 cycle, fitted. This quantity is the "average" phase. Bottom: the difference between the max/min, e.g., the fitted peak to peak oscillation amplitude, also data logged as "R:VDQPPA. During these 4 minutes, the setting on the 4-bump, or any other known setting changed. (Of course, one can not monitor everything that goes on in the tunnel, but to the best of my knowledge, nothing changed).

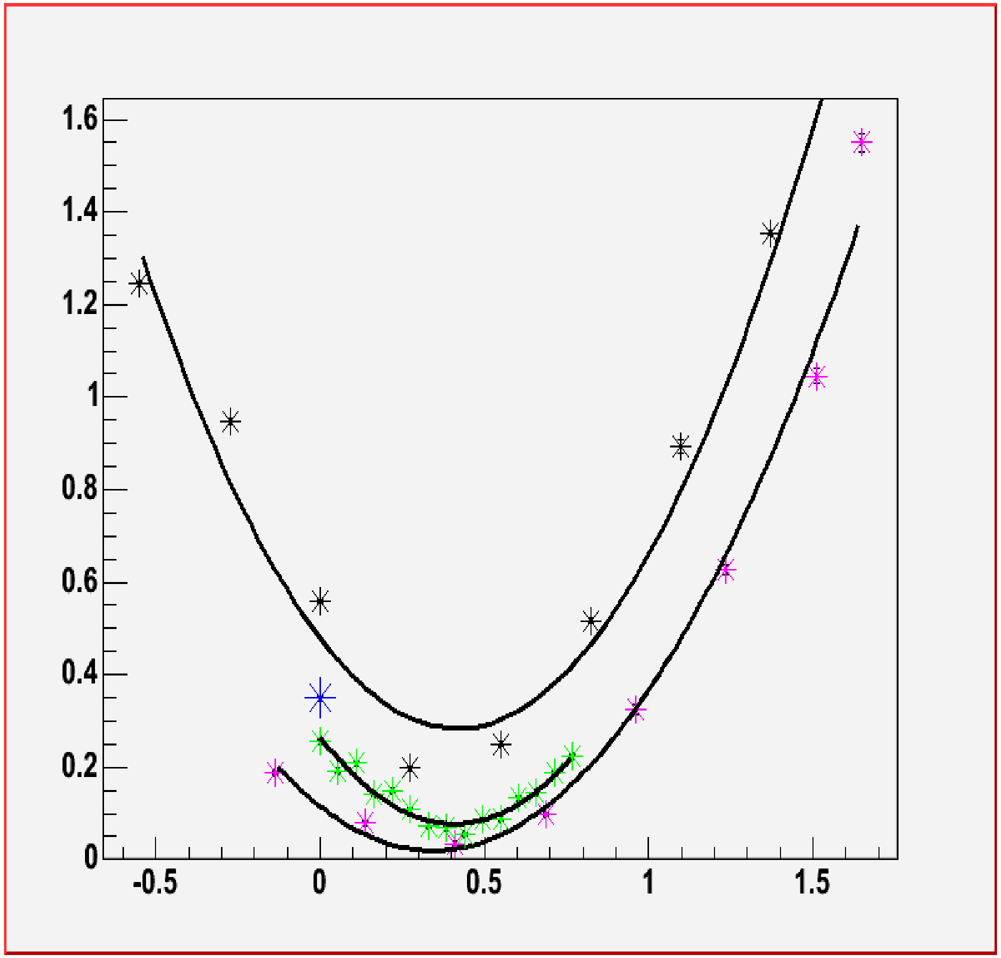
VDQ28 Phase Slippage..

- ~~A known feature. Martin Hu and Paul J. attempted to fix the problem by replacing the front-end computer board, no success.~~
- ~~Brian C will help…~~
- ~~Could affect the real beam longitudinal motion via the phase damper, at the system tries to damp out its own glitch.~~
- ~~A real nuisance if we want to reduce the VDQ28 oscillation below a few degrees (peak to peak!), reliably.~~
- ~~Lengthens considerably the time it takes to do a scan..~~

Fixed by R.F. experts.. (B. Chase..)

Fixed by B. Chase…

Implication: Repeat Measurements…



In these scans, taken yesterday late morning, we look for the optimum amplitude for the 5-bump (non-local), asymmetric, which mimics the QCLP type of bump.

On the X axis is the current at H518. On the Y axis the average, fitted peak-to-peak amplitude for the 0x23 cycles

The color code:

Blue dot, taken just before this scan, at relatively high emittance

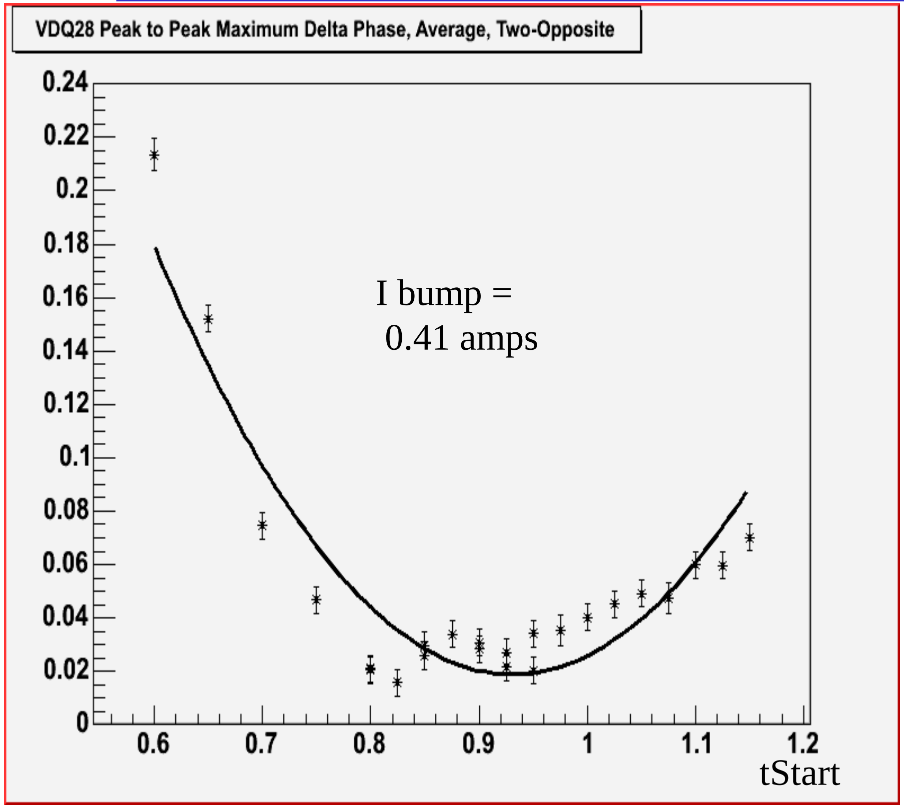
Black : first part of the scan

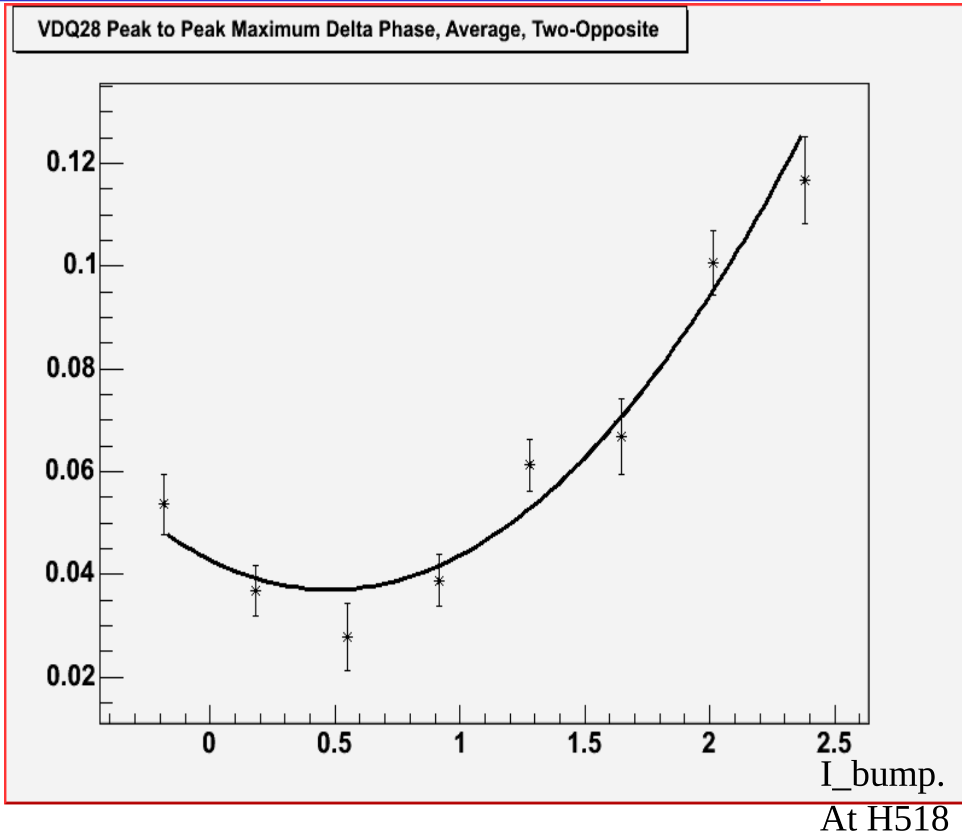
Magenta: 2nd part, back down in current.

Green: fine steps, taken later.

Good agreement on what the optimum current is.. (~ 0.42 +- 0.04 Amps.

Results for the "One Bump"





Left: Fitted peak-to-peak oscillation amplitudes versus the start time of the 5-bump, non-local, asymmetric, bipolar in the 0x23 cycle. The ramp starts at 0.48 seconds. The duration of the bump was 0.1 for the first pulse, 0.45 seconds for the second one. seconds, up/down time 0.1 seconds). A clear minimum is observed..

Right: Fitted peak to peak amplitudes versus the size of the 5-bump, local, symmetric (duration 0.45 sec) (Amps, at 518). This scan is incomplete and not accurate..

Scans done so far…. Bottom line

- Trouble is: No QCL / with QCL for the small intensity, small long. emittance is only ~ 0.5 degree. In fact, on slide, 10, there are no significant difference between QCL and the bipolar 4-bump. Note that the smallest synchrotron oscillation amplitude depends on many other factors, such linear bucket properties, and long. Emittance. Thus, scans can not be directly compared to one an other.
- **Optimum Shape: bipolar symmetric!!**
- The bipolar 4-bump requires about 1.5 Amps at H518, which corresponds to ~ 5.2 mm/H520, and 7.8 mm at H522 bump -> could work.
- The 5-bump, non-local, needs only I_H518 = 0.45 Amps -> relatively bigger change for smaller transverse bump, but unknow.. Un-intentional study…
- The 5-bump, local, does NOT need a 2 Amps at H518, optimum seems to be below 1 Amps -> good.
- Next step: repeat the correct 5-bump, local, and perhaps check that it is indeed close and the tunes looks good. If bump is small enough at the optimum current, use the 5-bump.

Beam Physics Issues: Motivation

- But, do we understand, quantitatively, why a ~ 6 mm 4-bump, corresponding to ~ 450 microns path length difference works? What is the scale of the perturbation? Why and how does a bipolar correcting transverse bump works ? Why is it "pseudo-inductive" e.g., correction is ~ $\delta B/\delta t$
- I was asked to write an "adaptive algorithm to minimize VDQ28 oscillations "automatically"…Not to do beam physics!
- This "adaptive" bit is a bit vague, and therefore hard, so this is why I started to do these scans without automated search for a extremum. We have the software tools and the computing resources to implemented automated search for extrema, but exploring this multi-parameter space is tedious and slow… Given the "phases glitches" and the smallness of the effect, this is even more tedious!
- Perhaps we can try to understand the physics a bit better, and eliminate solutions that have no chance to work. Let us go through a bit of beam physics modeling, explore possibilities…

Recap: What is VDQ28, how much orbit length?

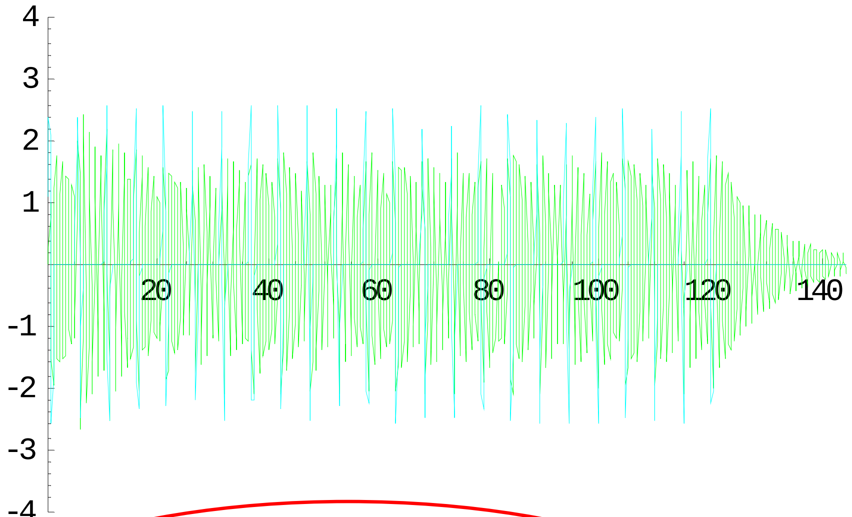
- The "28" is a currently a misnomer.
- It measures the synchrotron phase of the bunch with respect to revolution marker, at the base bad – 89 kHz, in degree
- Therefore, this fitted peak-to-peak VDQ28 Amplitude A_s satisfies
  - $\Delta L/L = (A\_s/360)\, f\_s/f\_r$
    - Where L is the orbit length, f_s is the synchrotron frequency (~ 1 Hz) and f_r is the revolution frequency.
  - Without QCL, without 4-bump, we observe A_s ~ 0.7 degree, or s ΔL of 62 μm, per turn
- When either QCL or 4-bump is used, one reduce these oscillation by ~0.3 degree, which is ~30 μm, per turn.
  - (The ~0.3 degree is for a ~ 4.8 microsecond bucket long!)
- With the 4-bump, 6 mm transverse deflection, the orbit changes length by only ~ 450 μm, per turn !
- How do we relate the synchrotron amplitude to the perturbation? Is there a glaring discrepancy between the ~ 30 microns (Synchrotron amplitude) and the 450 microns (linear optics)

Solving the 2nd order differential equation of motion..

- nus = 1.0;
- omega1SQ = 4*Pi * Pi * nus*nus;
- veffrf1 = -1.0 *omega1SQ;
- kDamp = -0.2;
- periodPerturb = 5.2;
- Phase0 = 0.48;
- sigmaRamp = 1.177*0.2;
- sigR2 = 2.0 * sigmaRamp*sigmaRamp;
- myPerturb = Sum[D[Exp[-(x-periodPerturb*i-Phase0)*(x-periodPerturb*i - Phase0)/sigR2],x],{i,0,23}];
- lengthSuper = periodPerturb * 22; (* 22 0x 23 cycles per super cycles assumed *)
- lengthStudy = lengthSuper + 30.;
- YPhiSol1 = NDSolve[{y''[x] Š veffrf1 * y[x] +y'[x]*kDamp + .5* myPerturb, y[0] == 0.0, y'[0] == 0.}, y, {x, 0., lengthStudy}, MaxSteps ® 500000]

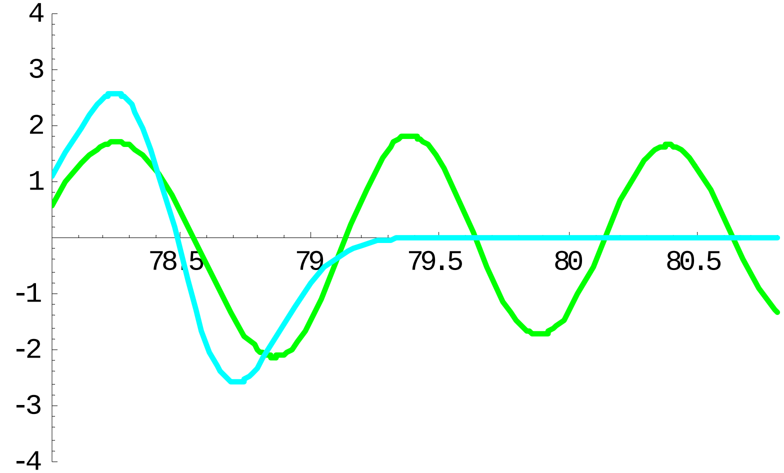
Simple Mathematica stuff….. Here, we simulate/solve a complete 2 min long supercycle. The perturbation is assumed to be the derivative of a Gaussian, e.g., bipolar. (perhaps wrong!!...)

Preliminary Mathematica result



1 Super cycle, 120 sec.
Blue is the perturbation,
Green is the response…

1 ramp.. Note: response has been multiplied by a factor of 20 !!!



- The way a forced, damped oscillator works…

Modeling the longitudinal perturbation…

- While the scale of the perturbation and the response of the system are plausible, we still need to understand the dynamics in a bit more details:
  - Model a : The change in the orbit due to residual MI B field is only partly compensated by local bumps, ~ MI ramp current. There is an overall orbit length change. QCL can correct for this because it also produce a global dipole field. If the 4-bump is applied in a straight section, the sign of the transverse bump should not matter. Luckily enough, the 4-bump is applied partly where the beam bends → we can shorten or lengthen the path length! (V. Lebedev, Stan,…)
  - **However, one then expect a correcting 4-bump pulse proportional to the MI B field, not it's derivative. → pulse shape is wrong..**

Modeling the longitudinal perturbation…(ii)

- A variant
  - Model b : The very low permeability of the shielding distorts, or "delay" the B field inside the RR beam pipe-> expect a different f(t)… Delayed by ~ 80 mSec, from a previous study done by S. Nagaitsev. Can this model support a bipolar correcting pulse ?
    - The tStart scan done yesterday does not support this model strongly..
  - Model c : The MI acts as a transformer on the RR, we induce current .. -> inductive recipe is O.K. (P.L.). In this case, changing the orbit length, turn after turn, make sense, because the energy of the beam stay put. (only magnetic perturbation and correction are applied).

Modeling the longitudinal perturbation…(iii)

- Modeling…
  - Model d: A bit more remote: Can the M.I./RR act as a really crummy Induction Linac ? That is, dB/dt inside the beam pipe (~ few (< 10) Gauss/sec or a up to ~2 10^{-3} Tesla) translates into ~ 2 10^{-3} V/m2 induction. Integrated over a path length determined by the size of the beam pipe, we get ~ E ~ 2 10^{-5} V/M. Summing over the length of the ring, up to 0.02 V/M per turn, at most. But the a 450 micron path length difference (or ~1.5 picosecond) in the 4.8 μsec, +- 1kV linear ramp translates to 0.3 mV per turn. So the scales could match!
- Conclusion: A correction proportional to B and/or dB/dt is plausible.

Do we care? What's the specs?

- The replacement of the QCL correction by a known 4-bump taught us that the magnitude of the required correction: per turn, only ~ 450 microns path length, per ramp, ~ 24 m (~75 ns) !!!!
- The bunch length is ~ 400 ns long, for ~30 eVsec, dP ~ 4 MeV
- Conclusion: Yes, we care!...(And now I finally understood what the problem is...)

Will this work?

- Yes, sort o, if,
  - A. The perturbation is " B field", correcting the orbit length makes perfect sense, we are correcting the same physical quantity: the path length, or time of arrival of a given particle with respect to the r.f. All good!
  - B. If "truly inductive", E field,
    - In a linear bucket, one still could improve by lengthening/shortening the orbit. As the synchrotron period is unique (~ 1 Hz) one can make a significant correction, during each 0.6 ns ramp, by adjusting the path length difference to a change in momentum. But not perfectly, the synchrotron period is too short (or we are taking intto account for the slip factor in the correct way.
    - In a square bucket, I don't understand how correcting the orbit length will work. The r.f. will not restore the momentum after correcting path length at random times!.

Wrapping up: More Studies !!

- More scans, with left-over pbars. (at least finish the incomplete 5-bump bipolar symmetric scans for the one bump..)
- Measure again the response function to a single (e.g. one cycle) perturbation. → Control the time-line. Needs at least 10 to 20 seconds between cycles → Costly. (Needs more than a few ramps, to mitigate the other unknown perturbation, and glitches)
- Use the 4-bump correction, bipolar ~ 1.2 Amps, instead of QCL, on the 0x23, for regular shots.
- Or the 5-bump, bipolar symmetric, once optimum amplitude is
- Extend to the other cycles…